Buck (A. H.)

ON THE

MECHANISM OF HEARING.

BY

ALBERT H. BUCK, M. D.,

INSTRUCTOR IN OTOLOGY IN THE COLLEGE OF PHYSICIANS AND SURGEONS, NEW YORK;
AURAL SURGEON OF THE NEW YORK EYE AND EAR INFIRMARY.

[*REPRINTED FROM THE N. Y. MEDICAL JOURNAL, JUNE*, 1874.]

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MECHANISM OF HEARING.[1]

It has often been said, and with entire justice, that no other part or organ of the human body is so beautiful in structure as the ear. Its tympanic membrane, its chain of ossicles, its wondrous labyrinth containing cavities within cavities and thousands of vibratile chords—all these together go to make up an organ of exquisite architectural beauty and one that is marvelously adapted to the purpose for which it is designed. This delicate organ, with its multitude of fragile elements, needs the most ample protection, and we find it, accordingly, buried deep in the bone whose name (*petrous*) tells the story of its hardness. Inaccessible, as it is, to the eye, the wondrous interior of the labyrinthine structures has long refused to give up its secrets. What we know to-day is the result of years spent in untiring energy, attended with repeated failures. One by one, however, the disputed anatomical points are being settled, and it is safe to say that the day is near at hand

[1] Prize Essay of the Alumni Association of the College of Physicians and Surgeons, New York, March, 1874.

when our knowledge of the anatomy of the ear will be as accurate as that which we possess of the eye. In fact, the progress which has been made, not only in the anatomy, but also in the physiology of the ear, has been so great during the past few years, that it will surely not appear a presumptuous thing to venture here upon an explanation—in some respects new—of how the act of hearing is performed.

FIG. 1.

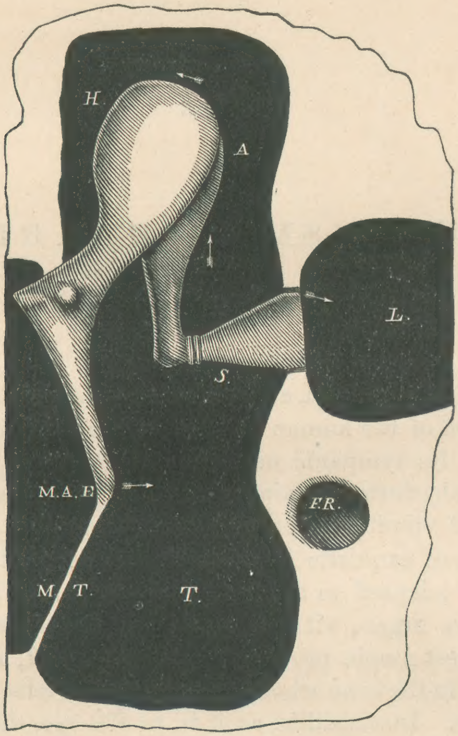


DIAGRAM SHOWING THE RELATIONS OF THE OSSICLES TO THE EXTERNAL AUDITORY CANAL AND LABYRINTH.

T, cavity of the tympanum; *L*, labyrinth; *M A E*, meatus auditorius externus; *H*, hammer; *A*, anvil; *S*, stirrup; *M T*, membrana tympani; *F R*, fenestra rotunda.

Before entering upon our topic, it will perhaps be best to state that for the sake of clearness we shall, as far as possible, avoid all discussion of disputed points. For the same reason we shall simply allude to or entirely omit all those points in anatomy which seem to have no important bearing upon the main questions at issue. Wherever diagrams will facilitate

the description, they will be used, though in most instances in such a form as rather to throw light upon the theory than to accurately demonstrate the anatomy. At the same time no essential anatomical point will be omitted or treated with undue attention.

The ear in mammals consists of three different cavities—the *external auditory canal*, the *tympanum*, and the *labyrinth* (Fig. 1). The first cavity is nearly cylindrical in shape; at one end it communicates with the outer world by a broad, free opening, while at the other it is entirely shut off from the cavity beyond (tympanum) by a thin, inelastic membrane —*the membrana tympani* (*M T*). The second cavity, so far as the naked eye can see, is a closed cavity, filled with air, which, through the medium of a minute canal (the safety-tube of the Eustachian canal) is kept at the same degree of density as the air on the outer side of the membrana tympani (Rüdinger). The length and height of this cavity are very nearly equal, but the breadth is much less than either. The outer side of this peculiarly-shaped cavity is composed chiefly of the membrana tympani, while the inner is a somewhat dome-shaped surface of bone, covered of course with mucous membrane. In this inner wall of the cavity are two openings—the one oval in shape, the other round—which lead by separate passages into the last cavity or system of cavities of the ear—the *labyrinth*. In the natural state these openings are closed, the upper one by the foot-plate of the stirrup, the lower by a delicate membrane (membrana tympani secundaria). The connecting link between the vibrations of air in the first cavity (or external auditory canal) and the auditory nerve, which is spread out in a portion of the third cavity (labyrinth), is formed by a chain of three ossicles, which arch the space separating the inner from the outer wall of the second cavity (tympanum). It is therefore essential to clearly understand the mechanism of these ossicles before we can discuss intelligently the more complicated mechanism of the labyrinth, and especially of that part of it called the cochlea.

Let us first take the sea-turtle and examine the simpler auditory apparatus (*see* Fig. 2) which we find in that animal. Here the substitute for the membrana tympani is situated al-

most immediately beneath the surface of the hard skin or shell on the side of the head, this animal having no external auditory canal. This substitute is nothing more nor less than the flaring end of a slender bone, about two inches in length, whose other end, likewise somewhat flaring, terminates in the labyrinth. This slender rod (*columella*) lies, throughout almost its entire length, in a bony canal, and fits it so accurately that

FIG. 2.

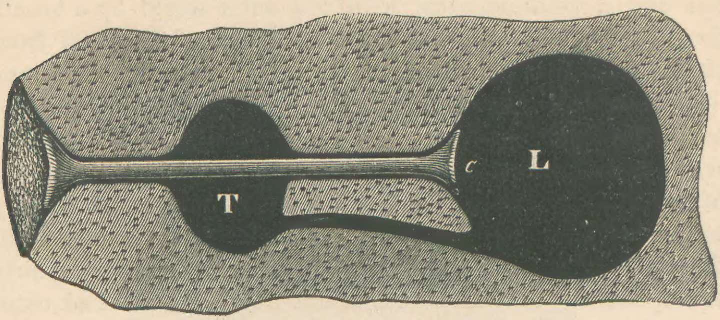


DIAGRAM OF SEA-TURTLE'S EAR.
T, tympanum; *L*, labyrinth; *c*, columella.

the only possible motion which can be communicated to the rod must be in the direction of its length. Pressure made at the outer end causes the inner end of the rod to project to a corresponding degree into the labyrinth; and, the moment the pressure is withdrawn, the rod, by reason of the highly-elastic ligaments which hold it in place, instantly returns to its original position.

The sea-turtle, then, furnishes us with a good example of the simplest substitute for the chain of ossicles, while at the same time the piston-like action of the rod throws out a hint as to the possible mechanism of the more complicated apparatus in the human ear.

Instead of a single rod, we find in the mammalian ear three distinct ossicles, called respectively the *hammer*, the *anvil*, and the *stirrup*. These three are connected together in a peculiar manner. The hammer, the first of the series, occupies such a position on the outer side of the tympanum that its handle (*s p* to *U*, in Fig. 3) projects from above downward as far as to the centre (*U*) of the membrana tympani, with

which it is intimately united (*see* also Fig. 1). In the next place the upper limit of this membrane consists of a band of fibres, which holds the hammer very firmly at a point midway between the end of the handle and the top of the head, and allows it to perform only limited rotary motions, inward and outward. The second ossicle, the anvil, grasps as it were the head of the hammer by means of a peculiar interlocking of their respective articular surfaces.[1] From the body of the anvil two processes project, the one backward to articulate with the posterior wall of the cavity, the other downward to articulate with the head of the third ossicle, the stirrup. While the articulation between the hammer and the anvil is of such a nature as to admit of almost no play of the articular surfaces upon each other, that between the long process of the anvil (*see* Fig. 1) and the head of the stirrup,[2] on the contrary, admits of full play between the two surfaces.

Fig. 3.

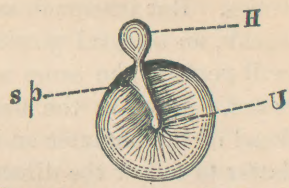


Diagram showing the Relations of the Hammer to the Membrana Tympani.

H, head of hammer; *U* (umbo), the tip of the handle of hammer, corresponding to the centre of the membrane; *s p*, the short process of the hammer.

Finally, the articulation between the foot-plate of the stirrup and the margin of the oval opening, which leads to the labyrinth, consists simply of a band of elastic fibres that span the narrow space which separates the border of the foot-plate from the margin of the window in which it fits.

What part, then, does this apparatus play in the function of hearing, and what are the mechanical effects of its action upon the fluid of the labyrinth? Obviously, to transmit accurately to this fluid body the same impulses which the membrana tympani receives. The mechanism may be thus described:

[1] Helmholtz, who was the first to describe the real nature of the malleo-incudal joint, compared it to "the joint used in certain watch-keys, where the handle cannot be turned in one direction without carrying the steel shell with it, while in the opposite direction it meets with only slight resistance."

[2] This articulation is not unlike the knee-joint, where the articular surfaces are separated by an interarticular cartilage (called *meniscus* in the stapedo-incudal joint).

Suppose a purely simple tone of one hundred vibrations per second to be sounded within hearing distance. The air in the immediate vicinity of the membrana tympani will be alternately condensed and rarefied one hundred times during the period of a second; or, in other words, the membrane itself will vibrate inward and outward the same number of times. But inasmuch as the handle of the hammer is, so to speak, an integral portion of the membrana tympani, it, too, will perform the same number of excursions inward and outward. Now, in the next place, the firm union between the head of the hammer and the body of the anvil will oblige the latter to follow the direction communicated to the head of the hammer by the excursion of its handle. A glance at the figure (Fig. 1) will show that on the anvil the direction of the motion imparted to it will vary according to the locality: thus, if the handle of the hammer be in the act of making an excursion inward, the top of the body of the anvil will be found moving in an outward and somewhat upward direction, while at the extremity of its long process (near the head of the stirrup) the motion will be chiefly upward, with somewhat of an inclination inward. The stirrup, whose head plays freely within the articular capsular ligament upon the end of this long process, will convert the impulse thus received into a motion, partly hinge-like and partly piston-like in its character.

It is, therefore, the function of the chain of ossicles to transmit to the fluid of the labyrinth whatever impulses may be communicated to the membrana tympani by sonorous vibrations in the air of the external auditory canal.[1]

Now, whatever may be the nature of these vibrations, it is evident, from the character of the attachments which hold the hammer *in situ*, that the only impulses which this ossicle is capable of transmitting are such as may be communicated to a single point in the handle, as, for instance, the tip. In the case, therefore, of a purely simple tone—by which is meant one that is perfectly free from all admixture of over-

[1] This doctrine, which was first put forth by Edward Weber, in 1851, was confirmed experimentally by Politzer, in 1868, and afterward by other observers.

tones—the point referred to would be subjected to a simple, pendulum-like motion. In the case of a complex tone, or of two or more tones produced simultaneously, it is not so easy to represent clearly to the mind's eye the movements which the point in question must execute. Prof. Alfred Mayer, of the Stevens Institute of Technology (Hoboken, New Jersey), has devised an experiment which almost renders these movements visible to the eye. It was executed in the following manner:

Placing a stretched membrane in a vertical position, and attaching fine threads of silk to its centre, Prof. Mayer put them moderately upon the stretch, and fastened them, each one to a tuning-fork (to one branch only) of different pitch. Upon sounding an organ-pipe (an instrument rich in overtones) on the other side of the membrane, he distinctly heard the tones of some of the forks. The moment the threads were cut, the tones ceased. After restoring the threads, the forks again vibrated audibly. When the organ-pipe was changed for one of a different pitch, it was observed that a different set of forks were excited to vibration.

While this experiment, then, furnishes us with a most valuable means of analyzing sound, it also clearly demonstrates that a given point in a solid body can be made to perform, at one and the same instant of time, the vibrations belonging to a number of tones of different pitch; in the present instance these were the fundamental note of the organ-pipe, together with its overtones. This complex vibration has often been compared to the changes which take place on the surface of a body of water. Thus, for instance, in looking at the ocean, we often observe that the surface is thrown into undulations by long and heavy swells; while upon them are numerous waves and smaller wavelets. Here, then, we see an illustration of the manner in which several kinds of waves may set in motion the same body of water at the same moment of time, without interfering with each other in any way.

Now, if we admit that the ossicles can vibrate in this manner in response to four or five tones, sounded simultaneously, there remains no serious obstacle to the belief that they can also vibrate in response to an almost indefinite number of

tones. In listening to conversation, to music, and to simple noises, our *ossicula auditus* are simply called upon to transmit at one and the same moment of time a varying number of impulses—for music, noises, and conversation, are all reducible to combinations of purely simple tones.

In the last place, how is it possible for the terminal filaments of the auditory nerve to analyze these impulses of such varying rates of vibration? Before answering this question, it will be necessary to take a glance at the anatomy of the last cavity mentioned above—the labyrinth—and to inquire into the mechanical effects produced upon its contents by the piston-like motion which we have attributed to the stirrup.

If we take a temporal bone, either in its natural condition or in the dried state, and endeavor by our eye to get some idea of the form, size, and relations of the labyrinth, we shall fail completely. There are only two points where we can get a glimpse of this portion of the ear, and these are at the two openings mentioned above as being situated in the inner wall of the middle cavity or tympanum. At all other points the various channels and cavities of the labyrinth are deeply embedded in the substance of the petrous portion of the bone. It is only by the aid of the hammer, the chisel, and the knife, that we can obtain the thin shell of bone which represents, as it were, the mould of the contained cavities. In this way we find that the labyrinth—we are speaking now only of its osseous boundaries—consists of a central cavity, not more than two lines in diameter, from one side of which spring, like arches, the three semicircular canals, while from the other side a canal leads into the snail-shaped body called the cochlea. In their natural state these bony cavities are filled with membranous structures and fluid. Thus, for example, the central cavity—or *vestibule*, as it is technically called—contains two distinct membranous sacs (*see* Fig. 4), which together do not quite take up the entire space of the cavity, but leave room, in the immediate vicinity of the foot-plate of the stirrup, for a certain amount of free fluid (Henle). The smaller of the two sacs, the *saccule* (*S*, Fig. 4), communicates with one of the membranous tubes of the cochlea, the *ductus cochlearis*. The larger one, the *utricle* (*U*, Fig. 4), is continuous with the

membranous tubes, which partially fill the semicircular canals; in fact, the two constitute an intercommunicating system of cavities, containing fluid, and bounded by membranous walls, so that pressure made upon the utricle will result in an increase of tension in the walls of the membranous semicircular canals.

If we uncoil the cochlea, and so convert it into a single straight bony tube, we shall find that its shape resembles that of an elongated truncated cone, whose larger base corresponds to the vestibular end of the cochlea, while the smaller would

FIG. 4.

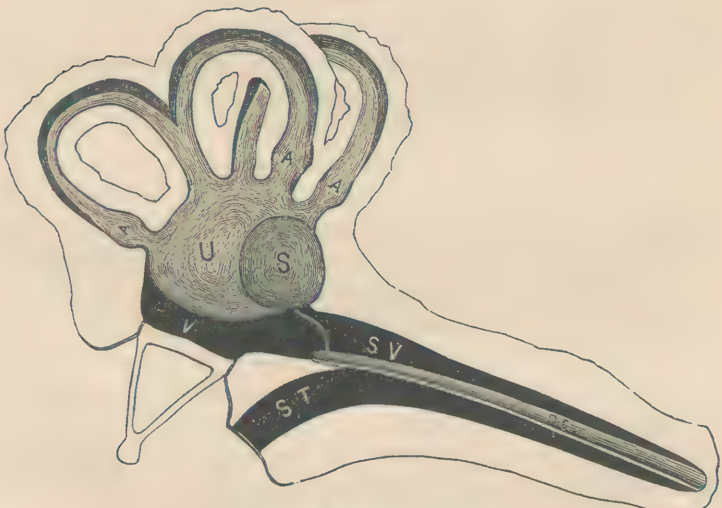


DIAGRAM OF THE LABYRINTH.

V, the vestibule, or central cavity, which is nearly filled by the utricle (*U*) and the saccule (*S*). Near the foot-plate of the stirrup, there is free fluid, which also extends up into the scala vestibuli (*S V*) of the cochlea. *D C*, the ductus cochlearis, which communicates by a slender membranous channel (canalis reuniens) with the saccule. Between the cochleal duct and the scala tympani (*S T*) is a narrow white band, representing the membrana basilaris. At the extreme tympanic end of the scala tympani, a faint white line indicates the position of the membrana tympani secundaria. *A*, *A*, *A*, ampullæ of the membranous semicircular canals, which, in these regions, fit pretty closely their surrounding bony walls.

represent the cupola, or highest point of the cochlea in its natural position. Now, there are certain membranous[1] septa which divide this single conical tube into three distinct and entirely separate channels, one communicating directly with the vestibule, while the other two are entirely shut off from any communication with it. In the first place, a sort of dia-

[1] In one instance partly membranous and partly osseous.

phragm divides the tube horizontally into an upper and a lower passage, each of nearly equal size. The upper one communicates by a broad mouth with the cavity of the vestibule, and for this reason has been named the vestibular channel or *scala vestibuli;* the lower follows its course toward the tympanum, but at the round window is shut off from it by a thin membrane—the *membrana tympani secundaria.* This lower channel is called the *scala tympani.* (Follow Fig. 4 for all these points.) A second diaphragm, which runs at an angle of about 45° with the first (*see* Fig. 6), divides the upper channel into the scala vestibuli proper and the *ductus cochlearis.* This last-named duct or channel is in reality a closed sac; its shape being that of an elongated truncated cone, whose larger base occupies the cupola, while the smaller lies at the very entrance to the cochlea in the vestibule. The ductus cochlearis may therefore be described as a body of fluid imprisoned within membranous walls, and containing certain peculiar structures, which will be mentioned in detail hereafter; and it may also be described as playing the part of a diaphragm between the fluid of the scala vestibuli and that of the scala tympani.

FIG. 5.

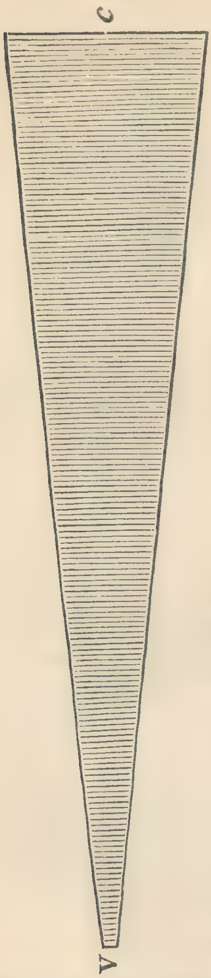


DIAGRAM OF THE MEMBRANA BASILARIS. *V*, its vestibular end; *c*, that in the cupola.

We have now completed our hasty sketch of the labyrinth as a system of channels and closed sacs containing fluid, and it still remains for us to speak of the peculiar structures contained within the ductus cochlearis—structures which have been shown to stand in direct communication with filaments of the auditory nerve, and which must therefore be considered as constituting the real terminal apparatus of hearing, in the same sense as the retina is the terminal organ of sight.

In the first place, the diaphragm, mentioned above as dividing the entire cochleal tube into an upper and a lower passage, will be found on microscopic examination to consist partly of bone and partly of membrane. The membranous portion of this diaphragm—if it were possible to dissect it out entire and spread it out before us—would be found to have a shape something like that given to it in Fig. 5. The small end *V* represents the commencement of the membrane near the round window, and the large end *c* its termination in the cupola. If we remove all the superimposed structures and examine this membrane under the microscope, we shall find it to consist of an almost countless number of rods, separated one from another by a glue-substance of but slight adhesive power. If we leave the superimposed structures *in situ*, and make a transverse section through the membrane, we shall find that it carries upon its upper surface the following peculiar anatomical elements (*see* Fig. 6).

1. A nearly central[1] arch, composed of two pillars, called respectively the *inner* and *outer pillars of Corti.* The shafts of these pillars are comparatively slender, but their bases and their heads are broad. The points to which attention should be called in the anatomy of these pillars are, their great strength and stiffness, compared with the other structures to be found in the ductus cochlearis; the constantly-increasing distance between the bases of the inner and outer pillars, as you go from the vestibule to the cupola; and, finally, the rounded character of the articular surfaces, where the heads of the inner and outer pillars come together—a peculiarity of connection which would indicate that a certain amount of play will be possible between the opposite heads of the pillars, in case the vibrations of the entire apparatus take place in a vertical plane.

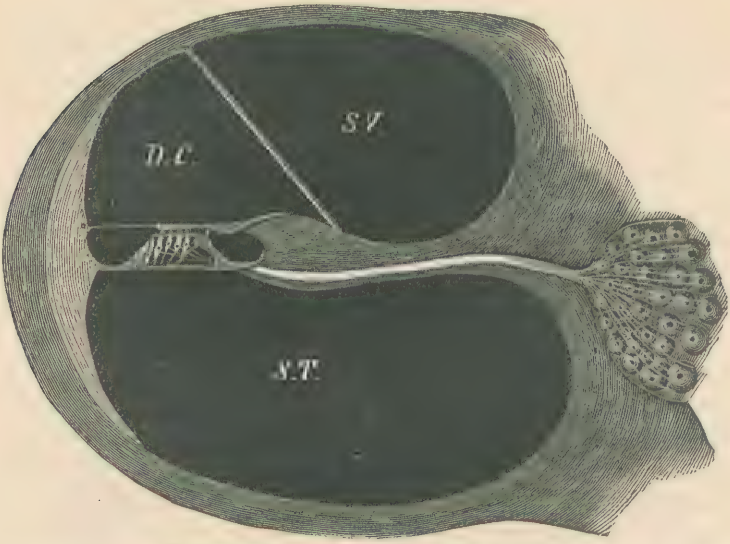
2. A peculiar fenestrated membrane, the *lamina reticularis*, which extends in an horizontal direction some little dis-

[1] The arch occupies such a position that the bases of the outer pillars stand very nearly in the centre or median line of the membrane. It is a significant fact that the outer rows of hearing-cells also occupy the central portion of the membrane, or that part which performs the greatest amplitude of excursion.

tance outward from the heads of the pillars of Corti, to which it seems to be in some way attached.

3. Five rows of ciliated cells, four on the outer side of the arch, and one on the inner side, close to the inner pillars of Corti. The four outer rows insert their heads into the openings of the fenestrated lamina reticularis in such a manner

Fig. 6.



Transverse Section of a Cochleal Whorl.

On the right, embedded in the substance of the bone, is a group of *ganglion cells*, through which the fibres of the auditory nerve pass before entering the *lamina spiralis ossea*. This latter is represented in the figure as a broad septum, separating the *scala vestibuli* (*S V*) from the *scala tympani* (*S T*), and containing a canal for the passage of the auditory nerve-fibres. While in the canal these fibres still possess a medullary sheath, but, on emerging therefrom into the *ductus cochlearis* (*D C*), they break up into naked axis-cylinders and terminate (as white threads in the drawing) in the single *inner* and four *outer hearing-cells*. The cilia of the four outer hearing-cells may be seen projecting through the *lamina reticularis;* those of the single inner cell (invisible in the drawing) project above the head of the *inner pillar of Corti*. The lamina reticularis is drawn as an horizontal projection (outward) of the upper portion of the head of the *outer pillar of Corti*. Underneath, these pillars rest upon the *membrana basilaris*, which terminates on the outer side in the *ligamentum spirale* (represented in the figure as a pale, crescent-shaped pad of connective tissue, fitting accurately to the surrounding shell of bone). The cilia of the hearing-cells come in contact above with the *membrana tectoria* or *Corti's membrane*, which springs from the upper side of the lamina spiralis ossea, near its free extremity, and terminates, by a thin extension, in the ligamentum spirale. *Reissner's membrane* is represented as a straight band, which stretches from the bony wall above, down to the upper side of the lamina spiralis ossea, and separates the ductus cochlearis from the scala vestibuli.

that the cilia stand up like bunches of hair at regular intervals along the surface of the membrane. Bundles of primitive nerve-fibrils from the cochleal branch of the auditory nerve have been traced to all five rows of ciliated cells, but to

no other structures in the ductus cochlearis. Hence the name of *hearing-cells*, which has very appropriately been awarded to these evidently the most important elements in the apparatus we are endeavoring to describe.

4. Simple epithelial cells, destined apparently to serve as a support to the lamina reticularis and to the outer and inner rows of hearing-cells.

5. A peculiar membranous structure, which starts from the upper side of the hook-shaped process of the *lamina spiralis ossea* and extends outward over the lamina reticularis. This membrane is mucoid (or doughy) in consistency, and, from the fact that it lies like a gelatinous veil over, and in contact with, the cilia of the hearing-cells, it is called the *membrana tectoria*[1] or covering membrane. As far as to the outer limit of the hearing-cells, this membrane retains its thick, doughy consistency, but beyond this region it is continued in the form of a very thin lamina to its line of insertion in the *ligamentum spirale.*

It is not necessary, to a clear understanding of the mechanism of the final act of hearing, that we should enter, any more fully than we have done, into the minute anatomy of the ductus cochlearis. What remains for us to do is to follow out, step by step, the mechanical effects upon the various labyrinthine structures of the piston-like vibrations of the stirrup, for it was here that we left off in our efforts to trace the effects of sound upon the apparatus of hearing.

The theory, which is universally accepted by physiologists in explanation of this point, is the one given by Prof. Helmholtz, and called, in honor of that distinguished physicist, "the Helmholtz theory of hearing."[2] The essential points in it are these: The component fibres of the membrana basilaris (Fig. 5) are to be considered in very much the same light as separate strings, which by a process of loading—that is, weighing them down with the pillars of Corti, the hearing-cells, etc. —have been tuned so as to vibrate in sympathy with all the

[1] Also *membrane of Corti.*

[2] *See* his work, entitled "Die Lehre von den Tonempfindungen," Braunschweig, 1870.

appreciable tones, from the highest to the lowest.[1] In fact, for every half-tone of our present musical scale there must be in the cochlea at least thirty-three strings to represent all its possible shades. When the stirrup, for instance, vibrates one hundred times in the second, it must excite to action that particular string, or group of strings, which is tuned to vibrate one hundred times per second. The vibration thus caused makes an impression upon the nerve supplying the vibrating part, and this in turn produces in the brain the sensation of sound. The damping of the vibrations, at the instant the irritation which produced them ceases, is attributed partly to the presence of a fluid medium, and partly to the fact that the vibrating structures proper (the strings of the membrana basilaris and the pillars of Corti) are pressed upon by cell-bodies which are not adapted for vibration.

The vertical vibration of the basiliar membrane is distinctly recognized in this theory ; but, in the preliminary description of the anatomy of the cochlea, mention is made of the existence of a small opening (*helicotrema*) in the cupola, through which a communication is established between the scala vestibuli and the scala tympani. Now, according to Kölliker and Reichert, the blind sac of the ductus cochlearis entirely fills the cupola (the vestibular half of it). This statement would seem, then, either to throw doubt upon the existence of such an opening, or to make it a channel of communication between the ductus cochlearis (instead of the scala vestibuli) and the scala tympani. The latter supposition, however, involving as it necessarily does a certain degree of longitudinal current in the fluid of the ductus cochlearis, cannot for a moment be entertained, as it would utterly overthrow any theory based upon the sympathetic vibration of the fibres of Corti's organ. On the other hand, if the blind termination of the ductus cochlearis does not entirely fill the cupola—as some authorities maintain—but leaves room for the fluid of the scala vestibuli to pass through a small opening in the septum into the scala tympani, the theory of a vertical motion for the membrana basilaris will still hold good, as the existence of the helicotrema

[1] The highest tones corresponding to the short strings near the vestibule, the lowest to the long ones in the cupola.

will simply serve to diminish the force of the vertical motion, but not to annul it. My own investigations, so far as they go, favor the view that no communication exists between the two scalæ in the immediate vicinity of the cupola, unless the opening, spoken of so vaguely by the authors, be microscopic in size.[1]

In the light of the histological discoveries, made since the time when Helmholtz published his last edition of the "Tonempfindungen" (1870), we would, with all due reserve, venture upon the following explanation of the mechanism of hearing in the cochlea:

We have described the labyrinth as a closed cavity, having but two channels of approach—the round and the oval window—one of which is filled up tightly by the foot-plate of the stirrup. Now, since, according to physical laws, the fluid contents of the labyrinth cannot be supposed to undergo diminution in bulk, under the pressure made by the foot-plate of the stirrup, we must assume—what has now been proved by direct observation[2]—that the elastic membrane of the round window affords the required yielding-point for this displacement.[3]

[1] To satisfy myself, if possible, on this point, I removed the cochleæ entire from the temporal bones of an infant, and softened them in a solution of chromic acid and hydrochloric acid (not more than five per cent. of each). When the earthy materials had been entirely removed from the bone, I placed the specimens in ordinary alcohol for a few hours, and with the razor divided them each into two unequal parts, the plane of section being at right angles to the base of the cochlea. In one of the cochleæ, the section passed so close to the bottom of the *cul-de-sac* of the cupola, that it was difficult to determine any thing satisfactory regarding the opening in question. In the other it was a comparatively easy matter, with an ordinary magnifying-glass, and after blowing out the free alcohol, to survey both the vestibular and tympanic surfaces of the septum, which in the cupola divides the two channels from each other. No trace whatever of any communication between the two passages could be detected.

The results of a single examination like this cannot, of course, be considered as sufficient to overthrow the statements of the anatomists. Nevertheless, the lack of definiteness in their descriptions of this opening (*see* Henle's "Anatomy" and Waldeyer's article on the "Labyrinth" in Stricker's "Histology"), taken in connection with its apparent absence in this one case, should lead to new investigations on this point.

[2] Dr. Charles H. Burnett, of Philadelphia, and others.

[3] This statement will be slightly modified farther on.

The first body to receive the impulse of the stirrup is the free mass of fluid which fills the unoccupied portion of the vestibule and the scala vestibuli. Without stopping here to discuss the effects of the stapedial [1] impulse upon the utriculus and semicircular canals, let us proceed at once to the consideration of the effects which this impulse will produce upon the cochlear structures.

In the first place a moment's thought will convince us that, in estimating the effects of the stapedial impulse upon the ductus cochlearis, we may totally disregard the sacculus and the *canalis reuniens.*[2] The uniform pressure of the fluid upon all sides of these last-named cavities will effectually prevent any thing like a current from the ductus cochlearis to the sacculus, or the reverse, through the canalis reuniens. The ductus cochlearis—that is to say, the upper and inner wall of it, or *Reissner's membrane*—is therefore subjected to a uniformly distributed pressure from above downward by the *centrifugal* (if I may so use the term) force of the fluid of the scala vestibuli. As it yields beneath this force, the incompressible body of fluid which fills the ductus cochlearis must in turn find its yielding-point in the entire membrana basilaris; for this and Reissner's membrane are the only two portions of the wall of the duct which are membranous, and therefore capable of yielding. Finally, the displacement caused in the contents of the scala tympani, by the depression of the entire membrana basilaris, is provided for by the presence of an elastic membrane (*membrana tympani secundaria*) at the larger end of this channel.

This brings us, then, face to face with the fact that the *entire* membrana basilaris (including high and low notes alike) is obliged to perform all the excursions which may be communicated to the stirrup or the membrana tympani by sonorous vibrations; or, to speak more minutely, with every tone sounded, every "organ of Corti" [3] must perform the excursions

[1] *Stapes* —a stirrup.

[2] The little canal (Fig. 4) which unites the sacculus and the ductus cochlearis.

[3] The term "organ of Corti" is used to desiguate the entire group of structures built upon the membrana basilaris.

which belong to that particular tone. But if that be true, it will be asked, why should not *all* the nerve-filaments send communications to the brain; or, in other words, why should we not hear all the notes of the scale whenever any one of them happens to be sounded? This is our answer, and we might add that it has been suggested to us by the peculiar relations of the membrana tectoria to the hearing-cells, and by the passing remark of Waldeyer (in the article referred to above) that "no portion of the labyrinth could be better adapted, by reason of its anatomical construction and position, to perform this function [that of a damper] than the membrana tectoria."

Although it be true that, with every note sounded, all the organs of Corti must perform the excursions belonging to that note, yet it must be remembered that the semi-gelatinous membrana tectoria, which rests upon the cilia of the hearing-cells, will likewise be obliged to perform these same excursions. Over one particular region, however, of the membrana basilaris this will not be the case, namely, in that portion where the thirty or more basilaris fibres are tuned to vibrate in sympathy with the note sounded. At this point the vibrations will be of sufficient vigor to throw off the membrana tectoria. So long, then, as that particular note is sounded, the cilia of the hearing-cells, in the region referred to, will receive a succession of taps from the membrana tectoria, or, to speak more strictly, will strike against this membrane. These blows constitute the true irritation of the auditory nerve. Wherever the blows do not take place, although the auditory nerve-filaments may be agitated in a direction at right angles to their length, there no sensations of sound will be communicated to the brain.

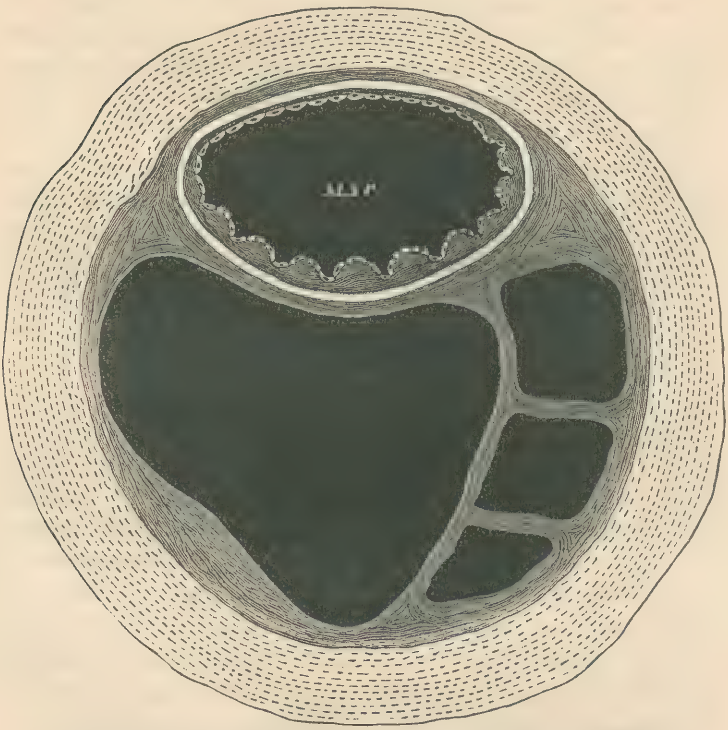
Before leaving the subject, we should like to venture a suggestion as to the function of the semicircular canals.

As is well known, it has been the custom until recently to consider these structures as governing the function of equilibrium (Flourens's theory). About three years ago Arthur Boettcher,[1] of Dorpat, proved by experiments upon living animals that this theory is incorrect. He proposed no new theory, but opened the way for others to do so if they wished.

[1] "Dorpater Med. Zeitschrift," vol. iii., part ii., 1872.

The first thing that attracts our attention in the anatomy of these organs is the peculiar relation of the membranous to the bony canals, the former occupying scarcely a third of the calibre of the latter. Then, in the next place, the space between the membranous canal and the bony walls is filled, not with free fluid, as is the case, for example, in the cochlea, but

FIG. 7.



TRANSVERSE SECTION OF SEMICIRCULAR CANAL. (Copied from Rüdinger.) *M S C*, membranous semicircular canal. (For further details, see the text.)

with a reticulated connective tissue, rich in blood-vessels and made up of large meshes containing fluid. In the vicinity of the mouths of these canals, however, it should be noticed that the membranous tubes hug the bone more closely (*see* Fig. 4). If we examine the mode of construction of the membranous canals, we find that the outer elastic wall (*see* Fig. 7) is lined with a sort of mucous membrane whose free surface undulates or is thrown into mounds, and carries a lining of ordinary

pavement epithelium. Another point worthy of notice is the absence of the undulations or mounds on that side of the canal which lies next to the bone—the side where dilatation cannot take place. These anatomical relations and the absence of nerves are certainly suggestive of the thought that the function of these canals must be a mechanical one. Is it not their function, we would ask, to protect the ductus cochlearis and the organs of Çorti from injury in cases where the stirrup is driven too violently into the oral window? Any pressure made upon the utriculus can only find a yielding-point in the elastic walls of the membranous semicircular canals; and, furthermore, if the latter were lined with a smooth instead of an undulating[1] epithelial surface, their distention would be followed by a rupture of the epithelial lining. Any sudden and loud noise, like the report of a cannon or a peal of thunder, would be likely to injure the cochlear structures, were not some provision made in the labyrinth for emergencies of this kind. As we have shown, the semicircular canals are not only admirably fitted to serve in the capacity of safety-valves, but their entire mode of construction, especially the absence of all nervous structures, would seem to exclude them from any higher office in the mechanism of hearing.

The suggestion of a recent writer (Hensen), that their function is that of secreting the labyrinthine fluid, has against it the fact that the epithelial cells lining the canals are of the pavement and not of the cylindrical or glandular variety.

[1] To establish this theory, it will be necessary to ascertain the circulation of blood in these parts, for the anastomosis of the veins surrounding the membranous canal with the veins of the bony walls is absolutely essential to it.